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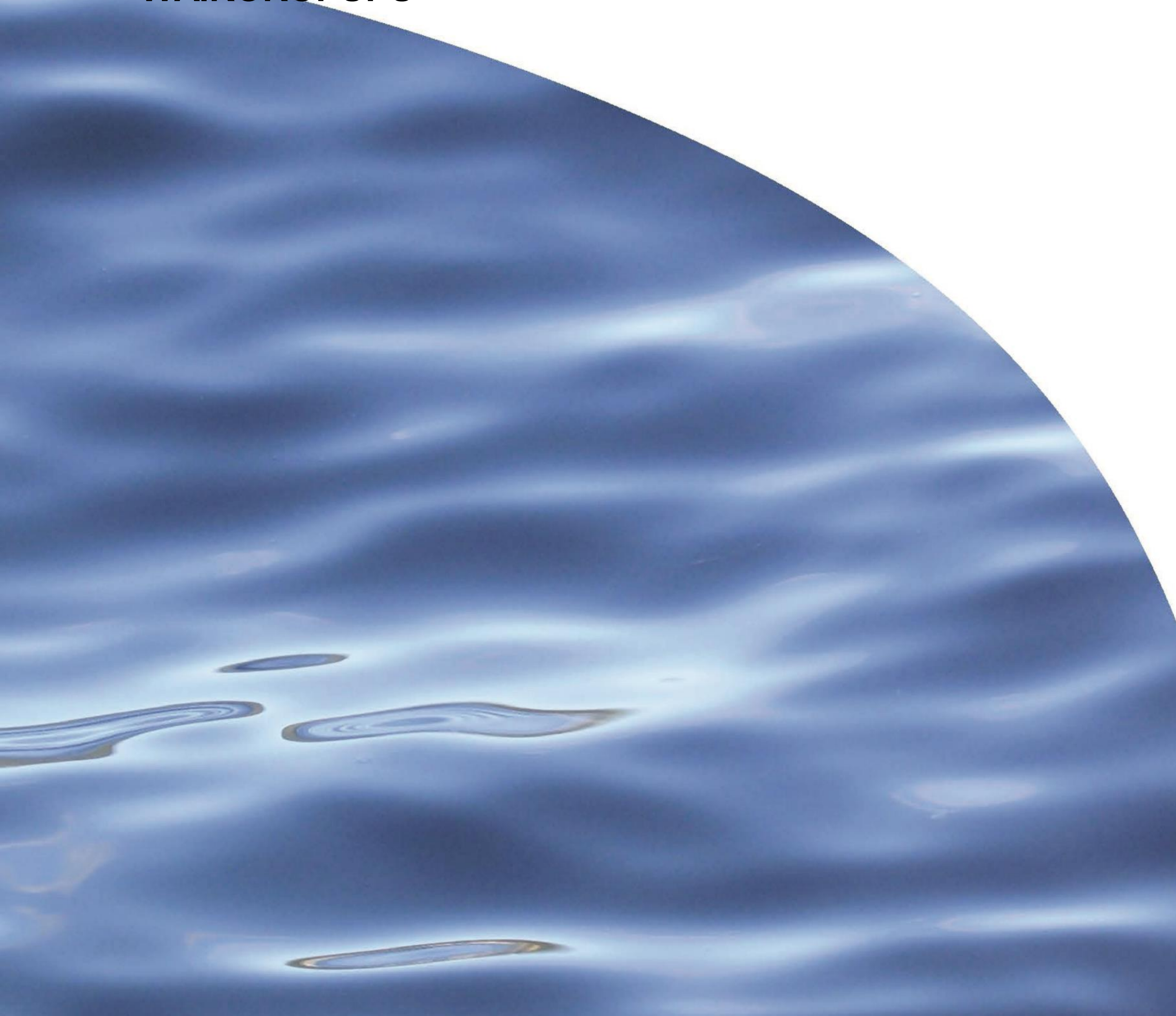
REPORT NO. 2977

A FRAMEWORK FOR SETTING WATER ALLOCATION LIMITS AND MINIMUM FLOWS FOR THE TAKAKA WATER MANAGEMENT AREA, AND AN ASSESSMENT OF THE GEOLOGICAL CONTRIBUTION TO THE NITROGEN LOAD TO TE WAIKOROPUPŪ



A FRAMEWORK FOR SETTING WATER ALLOCATION LIMITS AND MINIMUM FLOWS FOR THE TAKAKA WATER MANAGEMENT AREA, AND AN ASSESSMENT OF THE GEOLOGICAL CONTRIBUTION TO THE NITROGEN LOAD TO TE WAIKOROPUPŪ

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EXECUTIVE SUMMARY

Report Scope

Tasman District Council (TDC) is working to give effect to the 2014 National Policy Statement for Freshwater Management (NPS-FM). TDC has set up a Freshwater Land Advisory Group (FLAG) for the Takaka Water Management Unit (Takaka FMU) to enable involvement by the community and stakeholders in developing water quantity and quality management provisions for Takaka water resources. The Takaka FLAG has been considering existing and potential future water quantity and quality challenges in the Takaka water management area and attempting to develop solutions for managing water allocation and the water quality effects of land use activities. The FLAG will recommend draft planning provisions to TDC.

The Cawthron Institute was engaged by TDC to provide technical advice to the Takaka FLAG meetings on water allocation and environmental flow setting. This report provides a summary of the framework for water allocation and minimum flow that Cawthron recommended to the FLAG, and the scientific context for this advice.

Cawthron was also engaged by TDC to provide guidance on the likely size of the geological contribution to the nitrogen load to Te Waikoropupū (i.e. nitrogen sourced from the dissolution of rock). This report examines nitrogen levels in rock (marble, limestone, mudstone and coal measures) collected from different parts of the Takaka Valley and nitrate concentrations in springs and streams draining relatively unmodified areas in the upper Takaka Valley.

Environmental flows and water allocation

The NPS-FM requires councils and unitary authorities to establish freshwater objectives for their freshwater bodies and to set allocation limits for water quantity and quality to:

- safeguard life-supporting capacity, ecosystem processes and indigenous species including their associated ecosystems in sustainably managing the taking, using, damming, or diverting of fresh water.
- avoid any further over-allocation of water and phase out existing over-allocation.
- improve and maximise the efficient allocation and use of water.
- protect the significant values of wetlands and outstanding freshwater bodies.

To achieve these policies councils must define Freshwater Management Units and set freshwater objectives to:

- identify regional and FMU specific values (including the Ecosystem and Human Health compulsory national values).
- set environmental flows or levels for all FMUs (where, environmental flows for rivers and streams must include an allocation limit and a minimum flow, or other flows).

TDC has delineated zones within the Takaka FMU largely on a sub-catchment basis within the broader Takaka catchment.

Developing appropriate freshwater objectives for zones within the Takaka FMU to reflect community aspirations requires identification of in-stream and out-of-stream values, and decisions on in-stream values that are to be maintained in order to provide the basis for assessing the likely flow regime requirements to achieve the desired management objectives.

Instream values

Native fish diversity is generally very high in Takaka's coastal streams (with more than 10 native fish species in some cases), but comparatively low in the upper Takaka especially in and above the drying reaches. Water quality is generally good in streams draining the western ranges, but comparatively low in the Motupipi River and streams draining the Pohara Flats. The clarity of Te Waikoropupū was recognised as an exceptional value. Trout fishery information from the Cobb Dam re-consenting process and the National Angling Survey, suggests that a relatively small number of anglers use the lower Takaka trout fishery but rate it highly. Information on the whitebait fishery indicates that the Takaka River is one of the most important whitebaiting rivers in Golden Bay/Tasman Bay region. It was considered of 'major importance' to recreational fishers, and of 'significant or average importance' to commercial fishers. The Motupipi River also supports an important whitebait fishery.

Suggested indicative minimum flows and allocation levels

We have suggested the following framework for indicative minimum flow and water allocation levels to the Takaka FLAG:

- flow setting based on a historical flow method across all classes of instream ecological values
- minimum flow and allocation limits derived as percentages of naturalised 7-day MALF (mean annual low flow), with the percentages varying according to instream values
- minimum flow of 90-100% of 7-day MALF at sites with significant instream ecological values
- minimum flow of 70-90% of 7-day MALF at sites with moderate-high instream ecological values
- allocation limit of 10-20% of 7-day MALF at sites with significant instream ecological values
- allocation limit of 20-30% of 7-day MALF at sites with moderate-high instream ecological values
- allocation limits ultimately set based on an examination of the frequency and duration of low flows
- minimum flow equals a cease take condition
- 50% allocation rationing triggered when flow equals the minimum flow plus allocation limit. This was recommended only in zones where the flow recession is relatively slow.

Nitrate nitrogen in Te Waikoropupū Spring

Nitrate nitrogen concentrations in Te Waikoropupū have been measured since the early 1970s and have typically ranged from 0.3-0.5 mg N/L. Over the full length of the data record there is a statistically significant increase in the concentration of nitrate of 0.7% per year.

Nitrate concentrations in the springs would have existed prior to human settlement in the catchment owing to dissolution of N from geological sources and native vegetation. Geological sources of N (from the marble aquifer) represent only about 2% of the measured N load from the springs. However, breakdown/recycling of natural vegetation and other organic matter also contributes to the nitrogen load.

Given the information available we cannot make a precise estimate of the natural contribution of N to Te Waikoropupū. However, natural background levels of N were perhaps similar to, or higher than, that observed currently in nearby Spittal Springs draining largely undeveloped catchments (~0.22 mg/L).

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1. INTRODUCTION

Tasman District Council (TDC) is working to give effect to the National Policy Statement for Freshwater Management (NPS-FM 2014)[1]. As part of its progressive implementation plan TDC has set up a Freshwater Land Advisory Group (FLAG) for the Takaka Water Management Unit (Takaka FMU) to enable involvement by the community and stakeholders in developing water quantity and quality management provisions for Takaka water resources[2]. The Takaka FLAG has been considering existing and potential future water quantity and quality challenges in the Takaka water management area and attempting to develop solutions for managing water allocation and the water quality effects of land use activities. The FLAG will recommend draft planning provisions to TDC.

The Cawthron Institute (Cawthron) was engaged by TDC to provide technical advice to the Takaka FLAG meetings on water allocation and environmental flow setting. Co-author of this report Dr Roger Young of Cawthron has contributed technical advice to the Takaka FLAG discussions since late 2015, as well as being involved in water management decision making in the area over the last 18 years. This report provides a summary of the framework for water allocation and minimum flow that we recommended to the FLAG and the scientific context for this advice.

Cawthron was also engaged by TDC to provide guidance on the likely size of the geological contribution to the nitrogen load to Te Waikoropupū. (i.e. nitrogen sourced from the dissolution of rock). This report examines nitrogen levels in rock (marble, limestone, mudstone and coal measures) collected from different parts of the Takaka Valley and nitrate concentrations in springs and streams draining relatively unmodified areas in the upper Takaka Valley.

1.1. National Policy Statement for Freshwater Management

The NPS-FM signals a new direction for the management of freshwater resources in New Zealand. It requires regional councils and unitary authorities to establish freshwater objectives for their freshwater bodies and to set allocation limits in terms of water quantity and quality.

The National Policy Statement for Freshwater Management (2014) (NPS-FM) section B – Water quantity, requires councils to meet these four objectives:

[1] The NPS-FM is to be implemented by councils as promptly as reasonable, so as to be fully completed by 31 December 2025 (NPS-FM policy E1), though councils may apply for an extension until 31 December 2030 under certain circumstances.

[2] Including the Takaka River and its tributaries, ground waters within the limestone and alluvial aquifers, and adjacent coastal streams

1. to safeguard life-supporting capacity, ecosystem processes and indigenous species including their associated ecosystems in sustainably managing the taking, using, damming, or diverting of fresh water
2. to avoid any further over-allocation of water and phase out existing over-allocation
3. to improve and maximise the efficient allocation and use of water
4. to protect the significant values of wetlands and outstanding freshwater bodies.

To achieve these policies councils must set freshwater objectives using the process described in the NPS-FM:

1. define Freshwater Management Units (FMUs)
2. identify regional and FMU specific values (including the Ecosystem and Human Health compulsory national values)
3. set environmental flows or levels for all FMUs (where, environmental flows for rivers and streams must include an allocation limit and a minimum flow, or other flows).

TDC and the Takaka FLAG have been working through this process. Advice from Cawthron has focused on assisting the FLAG with identification of ecological values in the different zones within the Takaka FMU (i.e. part of point 2 in the list above) and specifically on deriving a framework to set minimum flows and allocation limits (i.e. point 3 in the list above).

2. DEFINING FRESHWATER MANAGEMENT UNITS

Zones within the Takaka Freshwater management unit have been delineated within the broader Takaka catchment by TDC (Figure 1), based largely on sub-catchment areas.

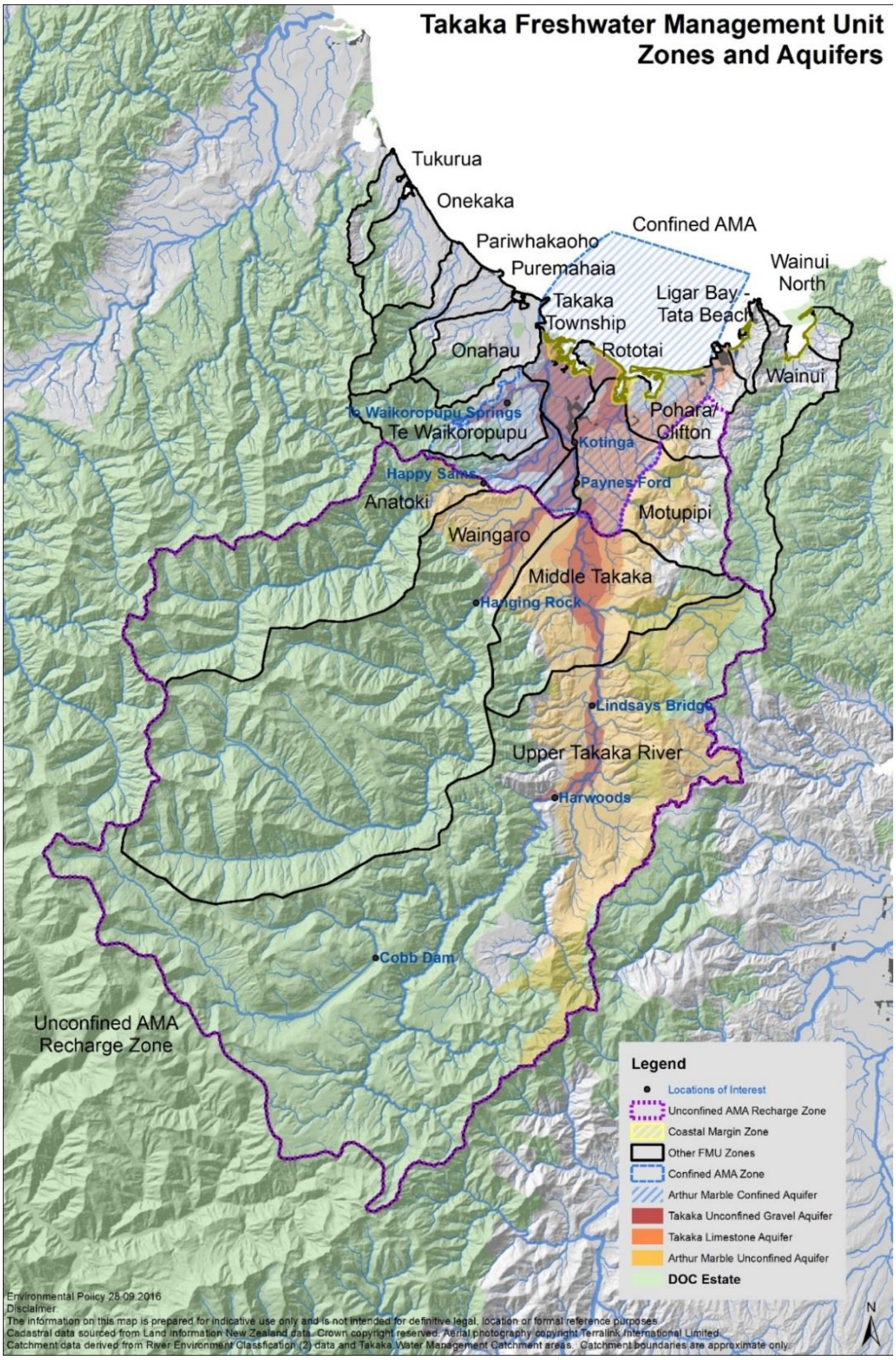

Figure 1. Freshwater management zones within the broader Takaka Water Management Unit that are being considered by the Takaka Freshwater Land Advisory Group (figure provided by TDC).

3. FRESHWATER VALUES AND OBJECTIVES

Developing appropriate freshwater objectives to reflect community aspirations is the critical first step in setting appropriate flow regimes (NPS-FM 2014; Ministry for the Environment Flow Guidelines 1998; Jowett & Hayes 2004; Biggs et al. 2008). This requires identification of in-stream and out-of-stream values, and decisions on in-stream values that are to be maintained, to provide the basis for assessing the likely flow regime requirements to achieve the desired management objectives. Once values have been identified, the NPS-FM (2014) requires these are matched by relevant attributes[3], leading to definition of objectives by assigning a minimum acceptable state for each attribute to maintain the identified values and setting (ideally) numeric limits for these attributes. Flow and/or flow-dependent physical instream habitat are likely to be key attributes for defining objectives related to the compulsory national value of ecosystem health, as well as non-compulsory values (e.g. fisheries).

Young (2006) provided an initial assessment of instream values and how these varied spatially over the broader Takaka catchment, and also presented suggested in-stream management objectives. These proposed management objectives were found to largely align with the objectives defined by the Takaka FLAG, although the zones within the Takaka FMU used by the Takaka FLAG were slightly different to the grouping of waterways presented in Young (2006).

When providing advice on prospective minimum flows and water allocation limits to the Takaka FLAG, Dr Young ranked the ecological instream values of each zone within the Takaka FMU generically into four categories (significant, high, moderate-high and moderate). This was essentially a subjective assessment based on the existing data and drew on the instream values identified in the earlier report (Young 2006) as well as on information from TDC's state of the environment (SoE) monitoring (Bruce 1987; Roberts 1993; MacGibbon 1998; Young et al. 2005; Young et al. 2010; Doehring & Young 2011; James & McCallum 2015); the Cobb Dam re-consenting process (Young et al. 2000); and the latest threat classification listings for native fish (Goodman et al. 2014). In order of priority, rankings were influenced by: native fish diversity, water quality and fishery values (Appendix 2). Cultural and recreational values were not explicitly included in the values assessment.

As a general overview of these factors, native fish diversity is generally very high in Takaka's coastal streams, with more than 10 native fish species in some cases, but comparatively low in the upper Takaka especially in and above the drying reaches. Water quality is generally good in streams draining the western ranges, but comparatively low in the Motupipi and streams draining the Pohara Flats, while the clarity of Te Waikoropupū was recognised as an exceptional value. Trout fishery

[3] measurable characteristics of fresh water, including physical, chemical and biological properties, which supports particular values.

information from the Cobb Dam re-consenting process (Young et al. 2000) and the National Angling Survey (Unwin 2009), suggests that a relatively small number of anglers use the lower Takaka trout fishery but rate it highly. Information on the whitebait fishery indicates that the Takaka River is one of the most important whitebaiting rivers in Golden Bay/Tasman Bay region. It was considered of 'major importance' to recreational fishers, and of 'significant or average importance' to commercial fishers (Kelly 1988). The Motupipi River also supports an important whitebait fishery.

Ideally freshwater objectives should include a quantifiable indication of the levels at which values are to be maintained, so that future monitoring can be used to assess fulfilment of the objectives. This concept is supported by Policy CB1 of the NPS FM (2014), which requires development of monitoring plans that 'monitor progress towards, and achievement of, freshwater objectives'.

Metrics relating to native fish diversity, population size structure and abundance, fishery use data and invertebrate community composition, along with water quality parameters are potentially useful for monitoring instream values to assess achievement of quantifiable management objectives, if these are set in the regional plan. It is worth noting that there is a large degree of natural temporal variability in some of these metrics, therefore small effects on fish and invertebrate populations are difficult to detect even with a well-designed and resourced monitoring programme. However, this does not diminish the need to monitor the response of in-stream values to flow management.

4. ECOLOGICAL FLOW REQUIREMENTS

Flow is the defining feature of rivers and streams, and influences many aspects of stream ecology, including transport of nutrients and food down a river system and the distribution and behaviour of organisms. Unfortunately, while scientific research in New Zealand has identified several ecologically important components of flow regimes, there is still insufficient ecological understanding to precisely quantify the likely ecological response of a given reduction in flow. However, existing knowledge provides a starting point for assessing flow regime changes and useful principles regarding aspects of flow regimes that need to be maintained (Appendix 1). The following list provides a summary of recognised ecologically important components of the flow regime (as described in more detail in Appendix 1):

- Large floods, which are responsible for maintaining channel form and large scale sediment transport. Often referred to as channel-forming flows, these are likely to be the size of an annual flood (Clausen & Plew 2004).
- Smaller floods and freshes, which flush fine sediment, periphyton and other aquatic vegetation. Often referred to as flushing flows, and are generally in the order of 3–6 times the median flow (Biggs & Close 1989, Clausen & Biggs 1997).
- Low flows, the period of minimum wetted habitat availability, but also potentially of relatively high productivity in the remaining habitat. In particular, the mean annual low flow (MALF) has been identified as an ecologically-relevant flow statistic for trout populations and native fish species (see Appendix 1), at least where the amount of suitable habitat declines at all flows lower than the MALF (Jowett 1990; 1992; Jowett et al. 2008), as is generally the case in small-moderate sized (MALF < 10 m^3/s), or braided, rivers. In larger rivers it has often been assumed that some parts of the river may be too fast/deep for most aquatic life even at MALF and lower flows might provide better habitat availability than under natural conditions, although recent research is challenging this assumption (Hayes et al. 2016).
- Flow recessions (higher than usual flow in the few days or weeks following a flood) may offer enhanced recreational opportunity and increased habitat area and food supply over and above that available at the MALF (Hayes et al. 2015; 2016).
- Flow variability, at a range of scales. This includes seasonal variability comprising the annual flow regime through to small-scale flow variations which are considered to be an essential element of the regime that should be maintained, avoiding long periods of artificial 'flat lining' at the minimum flow. In some situations the timing of flow variability may be a critical factor, e.g. to provide a stimulus for fish migrations.

4.1. Conceptual basis for setting minimum flow and allocation limits

The NPS-FM (policy B1) requirement for environmental flows for rivers and streams to include an allocation limit and a minimum flow is consistent with the Ministry for the

Environment Flow Guidelines (1998). These guidelines identified a minimum flow and maintenance of flow variability (via setting an allocation limit) as two critical flow regime parameters that need to be prescribed for sustaining in-stream values dependent on proper functioning of river ecosystems.

Minimum flows are usually required to maintain sufficient in-stream habitat to provide refuge to sustain populations during periods of low flow, but they are also intended to meet minimum water quality requirements of in-stream life. As discussed in Appendix 1, provision of flow variability at a variety of scales is required for maintenance of channel form, sediment and periphyton flushing, benthic invertebrate productivity, fish and bird feeding opportunities, and fishing opportunities. Flow variability can be managed with allocation limits or flow sharing rules to maintain some floods and freshes for flushing, and some degree of natural flow recessions, especially to avoid long periods of flat-lining of the minimum flow.

The hydrological effect of a run-of-river flow allocation is illustrated in Figure 2. By removing the allocated flow (yellow band) the blue sections of the hydrograph (above the allocation limit) drop down onto the blue section below the minimum flow. The result is that sections of the hydrograph display flat-lining at the minimum flow. Increasing the allocation rate increases the frequency and duration of flat-lining at the minimum flow with potential adverse consequences on invertebrate production, including the food supply for fish and birds.

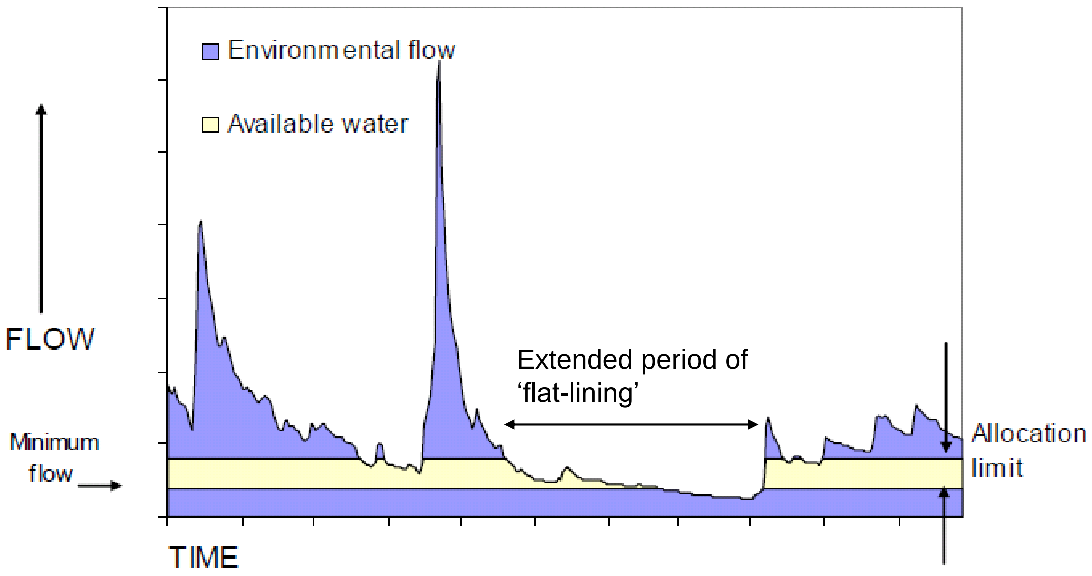

Figure 2. Illustrative hydrograph showing a minimum flow and the flow slice taken by the allocation limit. By removing the allocated flow the blue sections of the hydrograph above the allocation limit fall down onto the blue section below the minimum flow. The result is that sections of the hydrograph display flat-lining at the minimum flow.

The potential effects of abstraction are shown in Figure 3. Natural flows are represented by the blue line and flows after abstraction by the green line. The blue-shaded area represents the part of the hydrograph that potentially provides habitat for algal and benthic invertebrate production (following flood disturbance and resetting of communities).

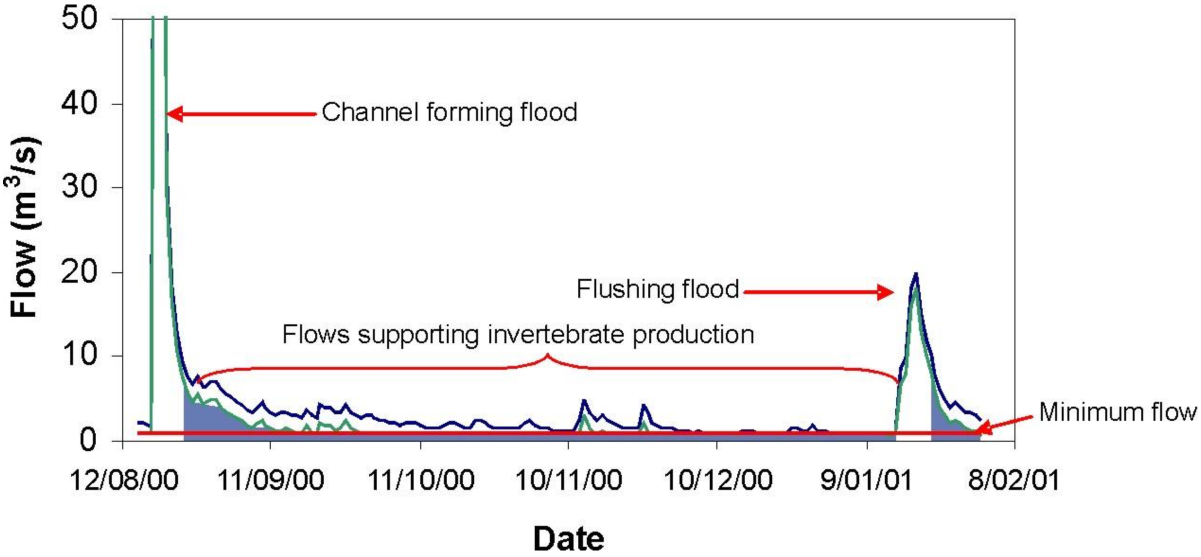

Figure 3. Illustrative hydrograph showing effect of abstraction on key flow features. Natural flows are represented by the blue line and flows after abstraction by the green line. The blue-shaded area represents that part of the hydrograph that potentially provides habitat for algal and benthic invertebrate production (following flood disturbance and resetting of communities).

Both the minimum flow and allocation rate are important for sustaining aquatic life and dependent values. The minimum flow should provide for at least 'minimum' annual, or seasonal, habitat and water quality requirements of the target in-stream values (e.g., fish species). Living space for fish is more likely to be limiting at the minimum flow, and with fish concentrated in the remaining habitat, there is the potential for increased competition and predation risk—which may translate to lower growth and survival. Of course all of these potential effects will worsen if flow is drawn below the minimum, and will be exacerbated the longer low flows are sustained (which can be influenced by the allocation limit). The minimum flow can be viewed as providing essentially a habitat refuge for fish during periods of low flow. It should not be viewed as providing adequate habitat to support fish populations over the long-term, if flow is consistently held at the minimum, because food supply for fish is likely to be reduced. Setting a minimum flow at or below the MALF with no safeguards for maintenance of flow variability has been likened to a doctor prescribing a patient's worst state of health as a life-time condition. Setting an appropriate allocation limit is the best approach to avoid this situation. The aim in setting the minimum flow is to provide enough suitable habitat for fish to survive in, hopefully fairly comfortably, for a relatively short period before flow increases again.

4.2. Flow regime assessment methods

The two most commonly used instream flow assessment methods for flow regime setting in New Zealand are historical flow, and habitat methods.

Historical flow methods

Historical flow methods involve setting minimum flows and allocation limits based on historical flow statistics. This method essentially assumes that the biological response is directly proportional to flow change (Figure 4). It is assumed that the ecosystem has adjusted to the ‘natural’ flow regime and that a reduction in flow will cause a reduction in the biological state (abundance, diversity etc.) proportional to the reduction in flow. It is usually also assumed that the natural ecosystem will only be slightly affected as long as the changes in flow are limited and the stream maintains its natural character. It is implicitly assumed that the ecological state cannot improve by reducing flow relative to the natural flow regime. Historical flow methods are low risk approaches aimed at maintaining an ecosystem in its existing state.

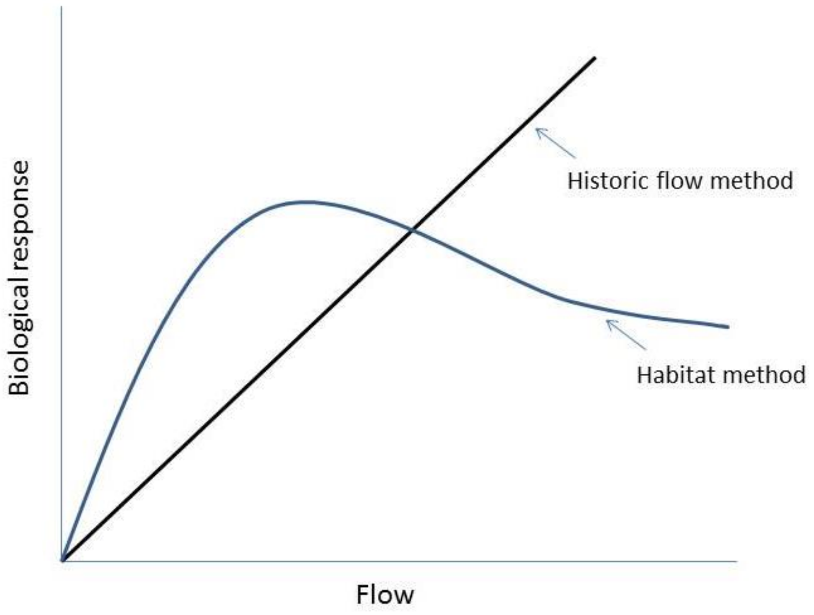

Figure 4. Hypothetical biological response to flow assumed in historical flow and habitat methods. The biological response is assumed to be directly proportional to the flow for the historical flow method and proportional to a metric of physical habitat for the habitat method.

Habitat methods

Hydraulic habitat models attempt to predict how the quality and quantity of physical habitat will respond to changes in flow. They involve a hydraulic component and a habitat component. The hydraulic analysis predicts how depth and velocity varies with flow at a series of points in a modelled stream reach. The habitat component involves assessing the suitability of these predicted depths and velocities for given target species or life stages, which is done by comparing predicted depths and velocities against criteria describing the physical habitat conditions used or preferred by the target organism.

Habitat methods assume that the biological response to flow change is dependent on the habitat preferences of the species in question (Figure 4). Consequently, it is considered possible for some level of flow reduction to result in a beneficial biological response, if this flow reduction results in habitat conditions (depths and velocities) that are more favourable for a given species. However, if there is no water in the stream, then obviously there is no habitat for aquatic species, so the biological response must begin to trend toward zero as flow is reduced beyond some threshold. This results in a typical humped, or asymptotic, response of habitat (and the assumed biological response) to flow (as depicted in Figure 4). The declining limb of this response, as flow reduces below the optimum or asymptote, is caused by water depths becoming too shallow and/or velocities becoming too slow relative to the habitat preferences of the species/life stage. The reduction in habitat conditions as flow increases above the optimum usually results from excessive water velocities. In large rivers (MALF >10 m^3/s), the habitat × flow curve may actually predict that physical habitat will be at a maximum at less than naturally occurring low flows (e.g. < MALF). Thus, in contrast to the historical flow method, the habitat method does not automatically assume that the natural flow regime is optimal for all aquatic species in a river. However, recent research has questioned the assumption that physical habitat can be improved by reducing flows compared to natural condition (Hayes et al. 2016).

Other instream modelling tools

There are a broad range of other modelling tools available to help address specific issues that may arise through changes to the flow regime. The need for these models depends on the system, including in-stream values identified, and on the degree of hydrological alteration. Most are likely to be worthwhile only in situations with moderate to high degrees of hydrological alteration and instream values. Beca (2008) contains descriptions of several of these modelling tools, addressing issues such as:

- fish passage / connectivity
- fish feeding and energetics
- periphyton biomass accrual and flushing
- sediment entrainment and transport
- seston flux
- groundwater

- dissolved oxygen and water temperature.

Since Beca's report, several benthic process models have become available that simulate the effects of altered flow regime on invertebrate and periphyton abundance/biomass (Olsen et al. 2013; Jowett et al. 2015; Hayes et al. 2015) while process-based fish feeding and energetics models have advanced further (Hayes et al. 2016). Dissolved oxygen levels can be a particular issue in spring-fed streams with prolific macrophyte beds. However, in our experience existing dissolved oxygen models have been found to be problematic to calibrate and apply in these spring-fed streams (Young & Doehring 2010; Young & Hay 2011; Doehring & Young 2012).

4.3. Selection of flow assessment methods

A guiding principle for selection of flow assessment methods is that while flow decisions should be science-based, the effort put into the science ought to reflect the relative values of the instream resources, and take the level of abstraction demand into account. This is consistent with the approach taken to flow management elsewhere in New Zealand (e.g. Jowett & Hayes 2004; Hurndell et al. 2007).

Habitat methods are more complex than historical flow methods and have typically been seen as preferable for flow assessment applications with high instream values and/or abstraction pressure. However, recently emerging research suggests that for drift-feeding fish (e.g. trout, smelt, inanga, dwarf galaxias, kōaro) traditional habitat modelling may underestimate the potential impacts of flow reduction on feeding opportunity and growth (Hayes et al. 2016), particularly in larger rivers. Other recent research in New Zealand suggests that in many cases habitat metrics from instream habitat modelling do not perform any better as predictors of fish populations than simple historic flow metrics, and in some cases appear to perform worse (Hayes et al. in prep; Jellyman 2015; Cawthron unpublished data). In addition, habitat modelling requires considerable field effort and experience and hence is more expensive than historical flow methods, which can be a barrier in the context of regional planning, although not for non-complying resource consent applications where instream values are high. Furthermore, habitat modelling results have remained contentious, particularly their perceived shortcomings in terms of biological realism.

For these reasons we recommended that the Takaka FLAG should use historical flow methods for setting minimum flows and allocation limits in the Plan, despite the significant instream values in some zones within the Takaka FMU.

4.3.1. Minimum flow setting

The MALF has commonly been used as a benchmark for flow setting in New Zealand since the early 1990s, although other low flow statistics have been used in some areas. As mentioned above, research in New Zealand has identified the MALF as an ecologically relevant flow statistic for trout populations and native fish species, at least where the amount of suitable habitat is predicted to decline through the MALF (Jowett 1990, 1992; Jowett et al. 2008), which is generally the case in small (or braided) rivers.

The MALF is indicative of the low flows likely to be experienced during the life cycle of most New Zealand freshwater fish, and provides an index of the minimum flow that can be expected from year to year. The lowest flow that a river falls to each year sets the lower limit to physical space available for fish populations, although the duration of low flow is also relevant. This annual limit to living space potentially sets a limit on average population abundance, assuming that populations are not limited by other factors. Theoretically, a change in available habitat will result in a population change only when all available habitat is in use (Orth 1987). Since a range of factors other than habitat, especially flood size and frequency, can influence species abundance, population densities are likely to be at less than maximum levels in many cases, although as habitat is reduced there must ultimately come a point where habitat becomes limiting.

Unfortunately, since scientific knowledge of the response of river ecosystems, and fish populations in particular, is insufficient to confidently identify levels of flow or habitat below which ecological impacts will occur, the choice of a habitat retention level is based more on risk management than ecological science. The risk of ecological impact increases the more that flow or habitat is reduced. When in-stream resource values are factored into the decision-making process then the greater the resource value, the less risk is generally deemed acceptable. With this in mind, Jowett and Hayes (2004) suggested that water managers could consider varying the percent habitat retention level (e.g. relative to MALF) depending on the value of in-stream and out-of-stream resources (i.e. highly valued in-stream resources warrant a higher level of habitat retention than lower-valued in-stream resources). This concept has been adopted by several regional councils in their flow-setting process (e.g. Greater Wellington, Hawkes Bay, Horizons and Environment Southland). A comparison of predicted habitat changes in different-sized rivers indicates that the risk of adverse effects from flow reduction is greater for fish communities in small streams (mean flow $< 5\ m^3/s$) than in larger rivers (Hurndell et al. 2007). Consequently, a more conservative retention level (level of maintenance) is advisable in smaller systems. Channel shape also affects the level of risk, with relatively lower risk of effects in U-shaped channels and higher levels of risk in rivers with a broad flat cross-sections where the wetted area will change more dramatically in response to changes in flow. Therefore, a more conservative protection level should be applied to rivers and streams with relatively flat cross-sections.

On the basis of the points discussed above, minimum flows are commonly set at the MALF or a proportion of it, usually based on percentage habitat retention and risk assessment. Retention of say 90% MALF is considered unlikely to result in detectable effects on existing population levels given the high degree of natural variability that is experienced in fish and invertebrate populations. Moreover, gauging error (the accuracy of flow measurement) is about 8% in any case. In contrast, retention levels of 50% MALF are more likely to result in a measurable effect on populations, especially where densities are high and thus physical habitat more likely to be an important limiting factor. The key concept is that the lower the retention level the higher the risk of detectable/noticeable effects.

4.3.2. Setting water allocation limits

In conjunction with minimum flow setting, consideration needs to be given to setting an appropriate flow allocation limit, or flow sharing rules, to maintain the key features of natural flow variability and avoid prolonged periods of flat-lining at the minimum flow. Setting the minimum flow at the MALF, or less, in the absence of appropriate allocation limits risks adversely affecting benthic production and the food supply for fish and birds. As discussed in Appendix 1, the median flow (or seasonal medians) can be viewed as providing an approximation of the typical habitat conditions able to be utilised to support benthic invertebrate production.

Maintenance of invertebrate production (which fish depend on for food) is arguably more dependent on allocation limits or flow-sharing rules, which ensure that the median flow is not substantially reduced by abstraction, than on the minimum flow *per se.* Higher flows maintain more wetted habitat to support invertebrate production and also maintain higher delivery rates of drifting invertebrate food items to drift-feeding fish. Consequently, sensible water allocation limits that regulate the reduction in mid-range flows by water abstraction, are likely to be critical for maintaining feeding opportunity for trout, and other drift-feeding fishes. Traditional habitat modelling may underestimate the potential impacts of water allocation on these fishes. This concept is receiving increasing support from research results recently emerging at Cawthron (Hayes et al. 2016, and Appendix 1). Results from this research suggest that where management objectives include sustaining feeding opportunity for drift-feeding fish, then consideration should be given to either higher minimum flows than commonly assumed necessary based on traditional habitat modelling results. Or, more conservative allocation rates (or flow sharing rules) should be considered to reduce impacts of abstraction on mid-range flows. Hence, we have recommended conservative allocation limits to the Takaka FLAG.

Methods for deriving allocation limits

There are various methods of deriving allocation limits in conjunction with a minimum flow. One method, which has been used by Horizons Regional Council (e.g. Roygard & Carlyon 2004; Hurndell et al*.* 2007), quantifies the expected increase in the frequency and duration of occurrence of the minimum flow in response to different total allocation rate scenarios. A possible alternative method, outlined in Jowett and

Hayes (2004, section 6, total allocation), involves trading off the magnitude of the minimum flow against the total allocation rate. If a low minimum flow is chosen then the allocation limit should be small to ensure that the minimum flow is rarely reached. Alternatively, if a large allocation limit is chosen then a high minimum flow should be set since the minimum flow is likely to be regularly reached.

The allocation limit and its effects on the frequency of occurrence and duration of the minimum flow will affect the surety of supply for abstractors (through abstraction restrictions), but also has the potential to have ecological effects, as discussed above. The method employed by Horizons Regional Council lends itself well to community consultation, whereby stakeholders can negotiate the frequency and duration of minimum flow occurrence that they deem acceptable, on the basis of relative in-stream values and out-of-stream water uses (including requirements for surety of supply).

The discussion above focuses on in-stream ecological flow requirements. Consideration should also be given to whether hydrological alteration of rivers will affect connectivity of rivers with riparian wetlands and groundwater, or other instream values (e.g. cultural).

Understanding the interaction between minimum flow and allocation limits

Those making decisions on water allocation need to understand the interplay between the minimum flow and allocation limit. The risk of adverse effects increases with decreasing minimum flow, increasing duration of minimum flow, and increasing allocation rate. The pros and cons of higher or lower minimum flows can be interpreted with respect to the following principles.

- A higher minimum flow results in higher levels of habitat retention, reducing the risk that the minimum flow will adversely affect the critical in-stream values and dependent fisheries and mahinga kai[4].
- On the other hand, a higher minimum flow decreases the security of supply for water to abstractors, assuming the same allocation rate.
- For any given minimum flow a higher allocation rate will increase the frequency and duration of occurrence of the minimum flow, reducing security of supply for abstractors and increasing the likelihood of adverse ecological effects.
- A lower minimum flow increases the risk that critical in-stream values will be adversely affected, so consideration should be given to setting a low allocation rate to help offset this risk.

The last two points above highlight the interplay between the minimum flow and allocation rate in influencing effects of flow alteration on river ecosystems.

[4] Traditional food and other natural resources and the places where those resources are obtained.

4.4. Water allocation limits and minimum flow precedents

Water allocation decisions in other parts of New Zealand provide some guidance on potentially suitable minimum flows and allocation limits. For example, conservative allocation limits specified in the Horizons Regional Council 'One Plan' are generally between 10–30% of MALF, and Environment Southland use allocation demand rising to 30% of MALF as a trigger to undertake a more complex flow assessment. Beca (2008) suggested that for rivers and streams with mean flow less than 5 m^3/s even a total allocation of 20–30% of MALF could be considered a high degree of hydrological alteration, depending on the instream values and baseflow characteristics of the stream. The findings of Hayes et al. (2016) suggest that conservative allocation limits (and flow sharing or abstraction step-down provisions) are likely to be at least as important as minimum flows for maintaining flows that support feeding opportunity for drift feeding fish.

Minimum flows of 90-100% of MALF can be considered environmentally conservative, while minimum flows lower than say 70% of MALF can be considered reasonably low minimum flows, particularly for small rivers (Roygard 2009). Jowett and Hayes (2004) suggested habitat retention levels of 90% of that at the MALF to retain instream values of high significance and retention levels as low as 60% for instream values considered to have relatively low significance. The decision on the Tukituki Catchment Proposal set minimum flows on the basis of 80–90% habitat protection levels relative to habitat sustained by the MALF for the most flow demanding species present (EPA 2015).

5. OTHER CONSIDERATIONS ON FLOW ALLOCATION

5.1. Naturalisation of flow statistics

Flow statistics (e.g. MALF) used in minimum flow and allocation setting should ideally be naturalised (i.e. adjusted to remove the influence of existing abstraction, so that they reflect the ‘natural’ flow regime in the absence of abstraction). If this is not done then there is the risk that the minimum flow will be incrementally ratcheted down over time, through successive flow assessments based on flow statistics that have already been diminished by previous abstraction. The location of the monitoring station relative to the water takes is important. In several situations within the Takaka FMU (e.g. Waingaro, Anatoki) the monitoring site is upstream of water takes and therefore measured flows do not require naturalisation. However, in other situations (e.g. Takaka township) measured flows are affected by upstream abstraction and flow statistics should be naturalised.

Naturalisation of flow statistics is challenging given that measurement of actual water takes have only recently been required in most regions and accurate information on the amount of water being taken, rather than just consented volumes, has traditionally been unavailable. Actual water takes are generally only a fraction of the consented volume, except potentially at times of peak water demand.

Accounting for groundwater takes on river flows adds another layer of complexity owing to time lags. Complex surface-water/groundwater interactions can also occur, with water being lost to, or gained from, ground – resulting in flow statistics varying along river segments.

5.2. Flow statistics: 7-Day or 1-Day

The MALF is generally defined as the average of annual contiguous flow minima over the period of record. The MALF is commonly calculated as either the 1-day MALF (annual minima) or the 7-day MALF (annual average of weekly minima (i.e. of a 7 day moving average). By definition the 1-day MALF is less than the 7-day statistic. Consequently minimum flows based on the 1-day MALF will be lower than those based on the same percentage of the 7-day MALF. However, by the same token, allocation volume derived as a given percentage of the 1-day MALF will be smaller than if based on the same percentage of the 7-day MALF.

With respect to setting minimum flow and allocation in the Takaka water management area we consider that the 7-day MALF is preferable to the 1-day MALF because:

- The 7-day MALF has consistently been used as the critical low flow statistic in TDC plans for rivers elsewhere in the region (e.g. TRMP Water - Policies - Chapter 30 sections 30.1.3.13 & 30.1.3.15).

- The 7-day averaging period aligns with TDC's water usage compliance monitoring, since TDC typically uses weekly usage to assess compliance with allocation.

5.3. Natural flow recession

All rivers/streams have flow features reflecting the catchment hydrology (geology, size, rainfall, groundwater relationship). Flow features include the flood pattern and flow recession during drought. The rate of flow recession after freshes will vary from catchment to catchment depending on catchment hydrology and the severity of drought. In drought, even after water abstraction is stopped, the river will naturally decline. The consequences of natural drought on habitat availability can be significant. This effect is natural and cannot be managed with run-of-the-river abstraction, whereas it can be mitigated by low flow releases from water storage schemes. With run-of-the-river abstraction, ceasing the taking of water when flow approaches the minimum flow can help to manage the effects of abstraction to a certain point, but as drought continues recession will naturally continue below the minimum.

5.4. Minimum flow equals cease take

The typical management response in other regions when the minimum flow is reached is to cease all non-essential abstraction. Abstraction for reasonable domestic and stock drinking requirements and for firefighting is generally allowed to continue. It is recognised that the flow may naturally drop below the minimum flow, but it is generally considered that these extreme low flow events should not be exacerbated by continued water abstraction.

Ceasing abstraction once the minimum flow is reached, rather than simply reducing abstraction, also provides greater certainty about the level of protection provided from effects of abstraction.

5.5. Abstraction step down

Having one or several step-downs in abstraction, in addition to the cease take at the minimum flow, can provide benefits to both water users and the environment. By reducing abstraction as flows decline toward the minimum flow, the rate of flow decline is slowed and the minimum flow is not reached as quickly (or not at all). Consequently, some water remains available to abstractors for longer, albeit at a reduced rate. Keeping flow above the minimum flow for longer also maintains greater area of the bed available for periphyton and benthic invertebrate production and greater feeding opportunity for fish, particularly drift-feeding fish (Hayes et al. 2016).

Stepping down abstraction is essentially a form of flow sharing, but is substantially more tractable from a management perspective than continuous incremental flow sharing. As with flow sharing the level of step down is arbitrary, but 1-to-1 flow sharing is generally considered equitable, since water users and the environment receive equal shares. In a step-down regime this would be equivalent to a 50% decrease in take when flow declines to a trigger flow equal to the minimum flow plus the total allocation volume.

6. RECOMMENDED WATER ALLOCATION FRAMEWORK

On the basis of the points discussed above, we suggested the following framework for minimum flow and water allocation setting to the Takaka FLAG:

- flow setting based on a historical flow method across all classes of instream ecological values
- minimum flow and allocation limits derived as percentages of naturalised 7-day MALF, with the percentages varying according to instream values
- minimum flow of 90-100% of MALF at sites with significant instream ecological values
- minimum flow of 70-90% of MALF at sites with moderate-high instream ecological values
- indicative allocation limit of 10-20% of MALF at sites with significant instream ecological values
- indicative allocation limit of 20-30% of MALF at sites with moderate-high instream ecological values
- allocation limits ultimately set based on an examination of the frequency and duration of low flows (similar to the surety of supply approach used by Horizons Regional Council (e.g. Roygard & Carlyon 2004; Hurndell *et al.* 2007)
- minimum flow equals a cease take condition
- 50% allocation rationing (step down) triggered when flow equals the minimum flow plus allocation limit. This was recommended only in zones where the flow recession is likely to be sufficiently slow to enable the rationing to have effect and avoid reaching the minimum flow and the associated cease take (i.e. a period from step down to cease take greater than 2-3 days).

A summary of how these recommendations would apply in the Takaka Water Management Area along with single specific recommendations are shown in Table 1. These recommendations are intended to provide a starting point for discussion by the FLAG rather than fixed levels.

Table 1. Summary of initial recommended minimum flows and allocation limits for different zones within the Takaka Water management unit to be used by the Flag as a starting point for their decision making.

Zone		Instream ecological value ranking	Recommended minimum flow	Recommended allocation limit	Rationing step	Cease take flow
AMA Recharge/Te Waikoropupū Springs		High	90% 7-day MALF at Main Spring (6895 l/s)	10% 7-day MALF at Main Spring (766 l/s)	No	7661 l/s
Waingaro		Moderate-High	80% 7-day MALF measured at Waingaro at Hanging Rock (2868 l/s)	20% 7-day MALF estimated at Waingaro upstream of Takaka confluence (550 l/s)	Yes, 50% cut at 3418 l/s	3143 l/s
Anatoki		Moderate-High	80% 7-day MALF measured at Anatoki at Happy Sams (1725 l/s)	20% 7-day MALF estimated at Anatoki at One Spec Road (341 l/s)	Yes, 50% cut at 2066 l/s	1896 l/s
Takaka Township		Moderate-High	80% 7-day MALF estimated at Takaka at Gravel crusher (4417 l/s)	20% 7-day MALF estimated at Takaka at Gravel crusher (1104 l/s)[c]	Yes, 50% cut at 5521 l/s[c]	4969 l/s[c]
Upper Takaka		Moderate	70% 7-day MALF measured at Takaka at Harwoods (1666 l/s)	20% 7-day MALF measured at Takaka at Harwoods (476 l/s)	No	2142 l/s
Motupipi		Moderate-High	80% 7-day MALF measured at Motupipi at Reillys (185 l/s[a])	20% 7-day MALF measured at Motupipi at Reillys (46 l/s)	Yes, 50% cut at 231 l/s[a]	208 l/s[a]
Coastal rivers	Tukurua	Significant	90% 7-day MALF (35 l/s)	10% 7-day MALF (4 l/s)	No	39 l/s
	Onekaka	Significant	90% 7-day MALF (104 l/s)	10% 7-day MALF (12 l/s)	No	116 l/s
	Pariwhakaoho	Significant	90% 7-day MALF (175 l/s)	10% 7-day MALF (20 l/s)	No	195 l/s
	Puremahaia	Significant	90% 7-day MALF (21 l/s)	10% 7-day MALF (2 l/s)	No	23 l/s
	Onahau	Significant	90% 7-day MALF (60 l/s)	10% 7-day MALF (7 l/s)	No	67 l/s
	Campbell	Significant	90% 7-day MALF (315 l/s)	10% 7-day MALF (35 l/s)	No	353 l/s
	Wainui	Significant	90% 7-day MALF (552 l/s)	10% 7-day MALF (61 l/s)	No	613 l/s
Waikoropupu River		High		Existing takes only		
Pohara/Clifton[b]		Moderate		Existing takes only		
Rototai[b]		Moderate		Existing takes only		
Ligar Bay/Tata[b]		Moderate		Existing takes only		
Wainui North		Moderate		Existing takes only		

[a] These flows are best managed using the correlation with water levels at the Takaka at Firestation groundwater bore, rather than measured flows which are strongly affected by aquatic plant growth in the Motupipi River.

[b] There are no flow recorders in these zones and therefore a policy of allowing no further takes is recommended.

[c] This allocation needs to include allocation in upstream zones. Note that these values assume that the rationing step and cease take are based on the sum of the minimum flow and allocation limit (or 50% of the allocation limit). An argument could be made that the allocation limit does not need to be added to the minimum flow at this site since takes may be downstream of the in-river values being protected.

7. A GEOLOGICAL CONTRIBUTION TO THE NITROGEN LOAD TO TE WAIKOROPUPŪ?

Nitrate nitrogen concentrations can potentially influence the growth and abundance of aquatic plants, and at higher concentrations can have direct toxic effects on some aquatic life. Therefore, management of nitrate concentrations, along with many other factors, is an important consideration in maintaining and enhancing freshwater values.

Nitrate nitrogen concentrations in Te Waikoropupū have been measured since the early 1970s and have typically ranged from 0.3–0.5 mg N/L (Young & Newton in review). Over the full length of the data record there is a statistically significant increase in the concentration of nitrate (Mann-Kendall trend test, increase of 0.7% per year) (Figure 5). The upward trend of nitrate concentration is still evident if the data just over the last 20 years are examined (increase of 0.5% per year) (Figure 5). If data from just the last 10 years are included in the analysis, there is a statistically significant downward trend in nitrate concentration (decrease of 1.4% per year) (Figure 5).

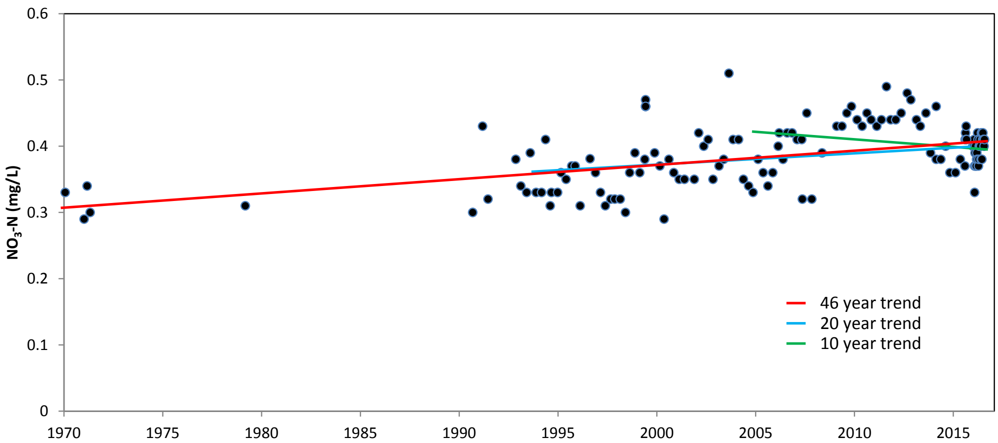

Figure 5. Nitrate nitrogen concentrations in Te Waikoropupū with outliers omitted, 1970-2016 (From Young & Newton 2016).

As part of the FLAG process, the effects of different land management scenarios on nitrate concentrations were modelled by Aqualinc and Landcare Research (Weir & Fenemor 2015). One of the scenarios in the model was ‘natural state’ and assumed that nitrate concentrations in Te Waikoropupū would be at, or very close to, zero under natural conditions. This assumption did not consider any natural sources of nitrogen, and specifically no geological sources of nitrogen.

In some situations geological sources of nitrogen (i.e. nitrogen sourced from the dissolution of rock) can constitute a significant component of the nitrogen budget of a catchment. For example Holloway and Dahlgren (1999) found that geological sources of nitrogen represented 30 to 50% of the soil nitrogen pool in a Californian catchment. Nitrogen released from bedrock contributed to an excess of available nitrogen relative to biotic demands, leading to nitrate leaching and elevated concentrations of nitrate in stream water (Holloway & Dahlgren 1999). Similarly, Dixon et al. (2012) found that marble contained a mean abundance of 4300 mg N kg, quartz schist 1600 mg N kg, biotite schist 4300 mg N kg, and garnet mica schist 4500 mg N kg. They considered that geologic nitrogen may represent a large and reactive pool with the potential for considerable impact on the geochemical system. Williard et al. (2005) also concluded that bedrock geology is an important factor to consider when assessing forest nitrogen dynamics at a broad landscape scale.

The karst/marble aquifer underlying the Takaka Valley is the source of water discharged from Te Waikoropupū. It is a very large aquifer (3.4 km^3 and up to at least 500 m thick) and water takes an average of 8 years to pass through (Stewart & Thomas 2008) providing significant opportunity for the chemical characteristics of the water to be influenced by the surrounding rocks.

Marble is relatively soluble in water. Calcium concentrations in Te Waikoropupū spring water are very high (64 g/m^3, Michaelis 1976), and at least an order of magnitude higher than what is typically seen in surface waters (Close & Davies-Colley 1990). Assuming that 60 g/m^3 of the calcium load from Te Waikoropupū is due to dissolution of marble within the aquifer, and given the 10 m^3/s average discharge from the springs, we calculate that around 19,000 tonnes of calcium is discharged from the main springs every year (60 g/m^3 x 10 m^3/s x 86,400 s/day x 365 days per year). Marble is predominantly calcium carbonate, so based on the molecular weight of this compound, we can assume that calcium represents about 40% of the total mass of marble. So, 19,000 tonnes of calcium is roughly equivalent to about 47,000 tonnes of marble dissolving within the aquifer and being discharged at the springs each year.

Based on an average concentration of 0.4 mgN/L, the total load of nitrogen being discharged from the main springs is around 126 tonnes per year (0.4 g N/m^3 x 10 m^3/s x 86400 s/day x 365 days/y). The contribution of geological nitrogen to this load will depend on the levels of nitrogen within the marble that is dissolved. If N concentrations are as high as those reported by Dixon et al. (2012), then the total nitrogen load (and more) could be attributable solely to geological sources (4300 mg N/kg x 47,000 tonnes/y = 202 tonnes N/y). However, if nitrogen levels in the marble are considerably lower than this then geological sources may be minor.

To determine the levels of nitrogen in marble and other rock that may influence water in the aquifer, analysis of the nitrogen content from 15 rock samples (9 marble, 2 limestone, 2 mudstone, 2 coal measures) from throughout the Takaka Valley was conducted at the GNS laboratory. The sites where the rock samples were collected are shown in Figure 6. The % nitrogen of the samples ranged from 0.003-0.05% (30-500 mg N/kg) (Figure 7). The values are considerably lower than the concentrations reported by Dixon et al. (2012).

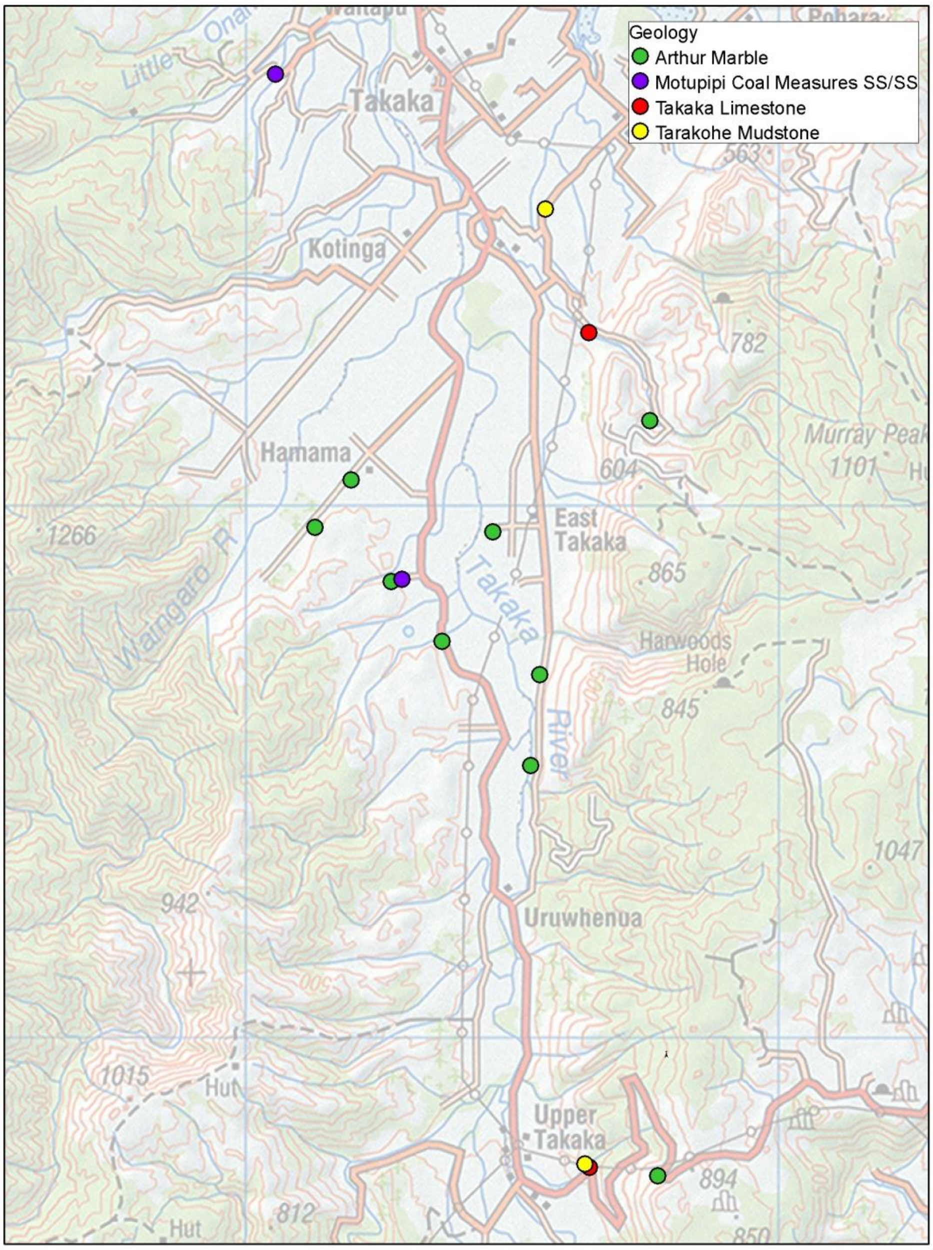

Figure 6. Map showing the location of rock sampling sites for determination of nitrogen content.

Based on the average nitrogen concentration in marble (66 mg N/kg) from these analyses, the nitrogen load associated with dissolution of 47,000 tonnes of marble per year would be 3 tonnes per year. This represents about 2% of the measured N load from the springs, so geological sources of nitrogen are likely to contribute only a small proportion (2%) of the load. However, it is possible that other natural sources of nitrogen, such as breakdown/recycling of natural vegetation and other organic matter, will also contribute to the nitrogen load.

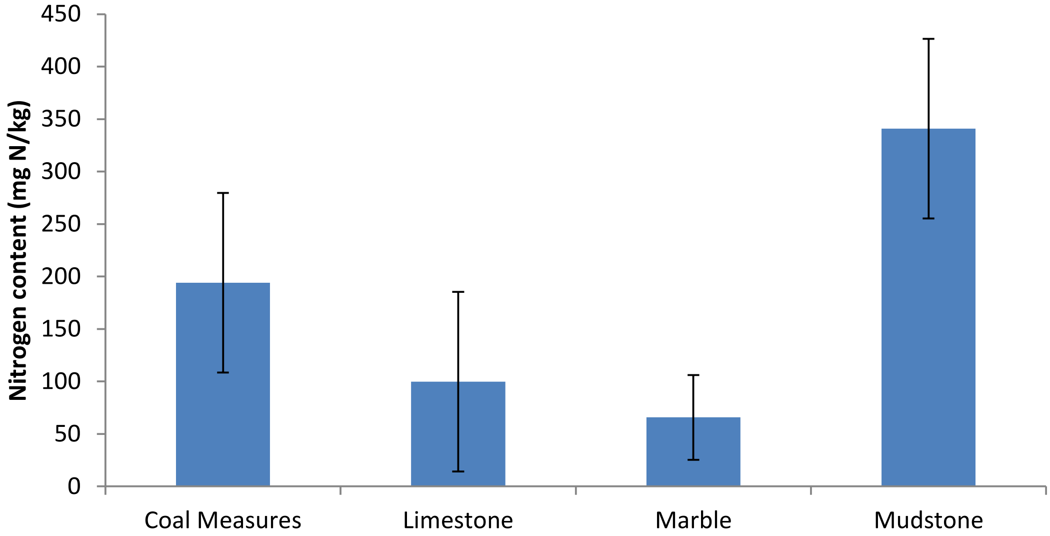

Figure 7. Nitrogen content in different types of rock collected from the Takaka Valley. Sampling site locations are shown in Figure 6. Error bars are standard errors.

To get an estimate of the potential size of other natural sources of nitrogen we examined nitrate nitrogen concentrations in a series of streams and springs draining either relatively unmodified parts of the Takaka Valley, or in areas of relevance to water entering or within the aquifer. The sampling sites for this analysis are shown in Figure 8 and were sampled by TDC staff just once on 7 September 2016. The samples were analysed at Hill Laboratories.

Table 2. Concentrations of nitrate nitrogen, dissolved reactive phosphorus and dissolved organic carbon at 5 additional sites in the Takaka Valley.

Site	**Nitrate-N (mg/L)**	**Dissolved reactive phosphorus (mg/L)**	**Dissolved organic carbon (mg/L)**
Whisky Creek	0.062	0.004	<0.5
Unnamed Creek	0.007	0.005	<0.5
Takaka @ Lindsays Bridge	0.032	<0.001	1.6
Spittal Spring	0.22	0.011	<0.5
Spring Brook	0.43	0.005	<0.5

Concentrations of nitrate-N in Whisky Creek, Unnamed Creek and Takaka @ Lindsays Bridge were low and similar to other rain-fed streams in the Tasman District draining catchments with limited to moderate levels of agricultural development (James & McCallum 2015). In contrast, concentrations of nitrate-N in Spittal Spring and Spring Brook were much higher. The elevated concentrations in Spring Brook may reflect agricultural development in the subcatchment feeding these springs. However, the catchment of Spittal Springs is largely undeveloped, and therefore the nitrate-N concentrations likely reflect the contribution of natural nitrogen sources from the recycling of nutrients found in organic matter deposited within the cave system feeding these springs and a small amount from geological sources. Similar recycling of nutrients from natural organic matter sources will be occurring within the Arthur marble aquifer that feeds Te Waikoropupū, so nitrate concentrations in the springs would not have been zero prior to human settlement in the catchment. Natural background levels of N were perhaps similar to or higher than that observed currently in Spittal Springs (0.22 mg/L), as the catchment of Spittal Springs is relatively undeveloped and water within the Arthur marble aquifer has a longer residence time than water in Spittal Springs. However, given the information available we cannot make a precise estimate of the natural contribution of N to Te Waikoropupū.

Figure 8. Map of the sampling sites for additional water quality measurements, including nitrate nitrogen concentrations.

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9. APPENDICES

Appendix 1. Key hydrological features of flow regimes for sustaining river ecosystems and in-stream values.

The hydrograph in Figure A1 shows key flow features and their physical and ecological function. Also depicted is an example of a minimum flow condition of 1 m^3/s, *c.f.* a natural mean annual low flow (MALF) of 1.15 m^3/s. Large floods, the size of the annual flood or larger, are important for maintaining the channel form and clearing terrestrial vegetation from the flood fairway. These are likely to be in the order of the mean annual maximum flow, with flows of more than about ten times the mean flow or 40% of the mean annual maximum flow beginning to move a substantial portion of the river bed (Clausen & Plew 2004).

Moderate-size floods (freshes) about 3–6 times the median flow (Biggs & Close 1989; Clausen & Biggs 1997) are also important for regularly flushing periphyton and fine sediment from the river bed. Maintaining the quality of benthic invertebrate habitat is the main ecological benefit of this process.

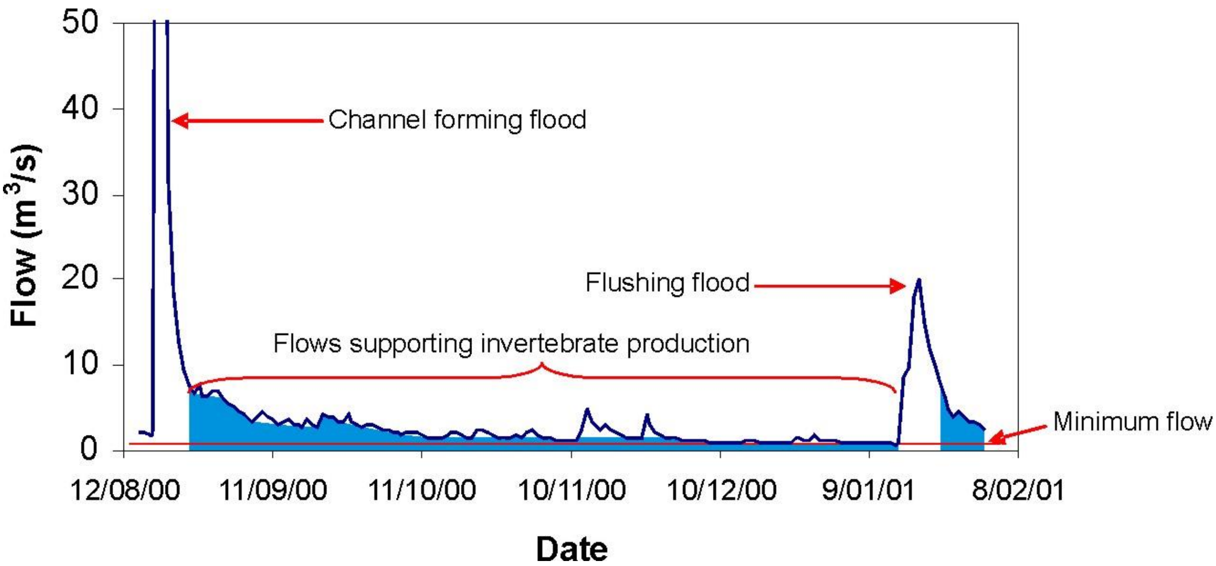

Figure A1. Illustrative hydrograph showing a minimum flow condition (1 m^3/s) and key variable flow features with their physical and ecological function. The blue-shaded area represents that part of the hydrograph that potentially provides habitat for algal and benthic invertebrate production (following flood disturbance and resetting of communities).

Lower flows, including the minimum flow, are of course important for maintaining fish and benthic invertebrate habitat. The MALF has been identified as an ecologically relevant flow statistic for trout populations and native fish species, at least where the amount of suitable habitat declines through the MALF (Jowett 1990, 1992; Jowett et al*.* 2008). This is generally the case in small (or braided) rivers. Jowett (1990, 1992) found that the quality of in-stream habitat (HSI, habitat suitability index, predicted by hydraulic-habitat modelling) for adult brown trout at the MALF was correlated with adult brown trout abundance in New Zealand rivers. The MALF is indicative of the low flows likely to be experienced during the generation cycles of trout and provides an index of the minimum flow that can be expected from year to year. The lowest flow that a river falls to each year sets the lower limit to physical space available for adult trout, although the duration of low flow is also relevant. This annual limit to living space potentially sets a limit to the average numbers of trout. This concept is intuitively sensible to anyone who has spent a lot of time looking for trout in rivers. Rivers that fall to very low flows each year hold few trout, while those that sustain higher low flows hold a lot of trout.

It seems reasonable that the MALF should be similarly relevant to native fish species with generation cycles longer than one year, at least in situations where habitat declines toward the MALF. If the minimum flow restricts habitat for any species, there is potential for a detrimental effect on that population. Research in the Waipara River in North Canterbury, where native fish habitat is limited at low flow, showed that the detrimental effect on fish numbers increased with reduced magnitude and increasing duration of low flow (Jowett et al*.* 2008). Research on the Onekaka River in Golden Bay also showed similar findings. When habitat availability was reduced by flow reduction, abundance of native fish species responded in accord with predicted changes in habitat availability in both direction and magnitude (i.e*.* eels and kōaro habitat was reduced and these species declined in abundance, while redfin bully habitat increased and so did their numbers; Jowett et al*.* 2008).

In contrast to long-lived species such as trout, some aquatic invertebrates have more than one cohort per year, and in New Zealand generally have asynchronous life-cycles (i.e*.* a range of different life stages are likely to be present at any given time). This allows them to rapidly repopulate areas following disturbance (e.g*.* by drift from tributaries and from other rivers by winged dispersal) (Williams & Hynes 1976; Scarsbrook 2000). Re-colonisation of some river beds by benthic invertebrates following disturbance has been reported to occur within 4–10 weeks (Sagar 1983; Scrimgeour et al*.* 1988). In other words, benthic invertebrates can respond relatively quickly to available habitat conditions, so their populations respond to more frequent limiting events (e.g*.* floods or low flows that occur over the time-scale of months). Flow variability influences the community structure of benthic invertebrates (Booker et al*.* 2014) and flow recessions following floods may also be important for contributing to benthic production. The latter point is illustrated by the blue-shaded area in Figure A1, which represents that part of the hydrograph that potentially provides habitat for periphyton and benthic invertebrate production (following flood disturbance and resetting of communities). However, the degree to which flow recessions will support significant benthic production depends on their duration. The most important habitat for benthic production is that which stays wet for longest, providing the current is not so great as to frequently move the bed or sandblast periphyton and invertebrates from the surface of stones. In rivers with very frequent flooding, the average duration of flow recessions may be too short for flows above the baseflow to wet margin habitat long enough to substantially contribute to benthic production, and so the base flow largely governs the amount of productive benthic habitat.

Because invertebrates colonise available habitat fairly rapidly (in the order of weeks to months), typical flows, in the mid-to-low flow range, are relevant for benthic invertebrate (and periphyton) production. The median flow (or seasonal median flows) is often viewed as providing an approximation of the typical habitat conditions experienced, and able to be utilised, by benthic invertebrates (Jowett 1992). This in turn may help define carrying capacity for fish and bird populations that feed on invertebrates. Jowett (1992) found that the quality of invertebrate food-producing habitat (HSI defined by Waters (1976) general invertebrate habitat suitability criteria) at the median flow was correlated with trout abundance (Jowett 1990, 1992).

In addition, recent research at Cawthron (Hayes et al. 2016) suggests that drift-feeding fish may be more sensitive to flow reductions around the MALF to median flow range than was previously recognised. This research employed a suite of models that predict how changes in flow affect invertebrate drift and energetics of drift-feeding trout (Hayes et al. 2007). Both water velocity and drift concentration (the number of invertebrates per unit volume of water) decline with flow reduction and the two factors combine to reduce the rate of invertebrates passing through the cross-sectional foraging area of a drift-feeding fish. While habitat availability for adult trout in larger rivers is often predicted to peak at flows in the low to median flow range, net rate of energy intake (NREI) for drift-feeding trout in the Mataura River was predicted to continue to increase across this flow range (Hayes et al. 2016). Net rate of energy intake is a fitness metric that translates to growth and potential abundance. These findings suggest that allocation of water in the mid-to-low flow range (in the order of about 0.5 × median to MALF) has the potential to adversely affect feeding opportunity, growth, and ultimately, carrying capacity for drift-feeding trout. These findings are based on a mechanistic understanding of ecosystem processes, so inferences from the models ought to apply to drift-feeding native fish (*e.g.* smelt, inanga, dwarf galaxias, kōaro) as well, although where adult trout are present, flows set for them ought to adequately provide for the flow needs of these smaller native fish. Principles arising from the mechanistic drift foraging NREI model are of less relevance for most of our other native fish species, which are mainly benthic feeders.

A recent analysis suggests that flow variability appears to be an important factor influencing community structure for both migratory and non-migratory fishes in New Zealand (Crow et al*.* 2013). While low flow was found to be an important explanatory variable for community structure, flow variability was substantially more influential than the effects of low flow, particularly for non-migratory fishes (Crow et al*.* 2013); essentially non-migratory species are less likely to occur in rivers with frequent floods. Flow variability may also provide a stimulus for fish migrations. Flows in the order of 2–4 times the median or preceding baseflow have been associated with movement of several fish species in New Zealand (Snelder et al*.* 2011). The distance that can be covered by migrating fish during a flow event is obviously related to the duration of elevated flows. Consequently, if water abstraction causes more rapid flow recessions it may curtail migration opportunity.

Appendix 2. Summary of ecological value rankings for each of the zones within the Takaka FMU. Limited or no data is available in some of the zones. Therefore, in these cases the assessment is based on expected conditions based on personal experience and data from neighbouring or similar zones.

Zone		**Native fish diversity**	**Water quality**	**Fishery values**	**Overall Instream ecological value ranking**
AMA Recharge/Te Waikoropupū Springs		High	Significant	Contribution to downstream whitebait and trout fishery	High
Waingaro		Moderate	Good	Valued trout fishery	Moderate-High
Anatoki		Moderate	Good	Valued trout fishery, eel viewing	Moderate-High
Takaka Township		High	Good	Valued whitebait and trout fishery	Moderate-High
Upper Takaka		Low (affected by drying zone)	Good (some effects of Cobb Scheme on water clarity)	Trout fishery	Moderate
Motupipi		High	Moderate	Valued whitebait fishery	Moderate-High
Coastal rivers	Tukurua	Significant	Good	Low	Significant
	Onekaka	Significant	Good	Low	Significant
	Pariwhakaoho	Significant	Good	Low	Significant
	Puremahaia	Significant	Good	Low	Significant
	Onahau	Significant	Good	Low	Significant
	Campbell	Significant	Good	Contribution to downstream whitebait and trout fishery	High
	Wainui	Significant	Good	Low	Significant
Waikoropupu River		High	Good	Valued trout fishery	High
Pohara/Clifton[b]		Moderate	Moderate	Low	Moderate
Rototai[b]		Moderate	Moderate	Low	Moderate
Ligar Bay/Tata[b]		Moderate	Moderate	Low	Moderate
Wainui North		Moderate	Moderate	Low	Moderate